Impact of Pressing Regime and Substrate Type on Bond Quality of Decorative Veneer

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The choice of optimal pressing regime for certain types of substrate is of great importance in production of veneered panels. In this paper, the impact of pressing regime on the bonding strength of beech and oak veneers, glued with urea-formaldehyde (UF) adhesive, on medium-density fiberboard (MDF), and moisture-resistant MDF (MR MDF) substrates was examined. The analyses showed a generally higher bond strength with oak veneer compared to beech veneer, which was also the case with regular MDF compared to moisture-resistant MDF. Multivariate analysis of variance (ANOVA) showed that with beech veneer, all of the used regimes produced better results on regular MDF compared to moisture-resistant MDF. In contrast, with oak veneer, the influence of pressing regime had a more noteworthy impact than the type of substrate used. These results indicated that the use of MR MDF as substrate in combination with UF adhesive was inadequate.

Keywords: Veneer; Medium-density fiberboard; Pressing regime; Bond strength

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INTRODUCTION

Veneered panels are often used as elements in interior decoration and as elements of building joinery (*e.g.*, doors). In comparison to solid wood, veneer panels generally have a lower cost (given that only a thin lining is made of solid wood) while maintaining the aesthetic features of solid wood. In contrast, the greater stability of veneered panels towards shrinking, checking, and warping of veneered panels enables them to achieve additional economical savings through the reduction of panel thickness (relative to panels of the same dimensions made from solid wood) (Ozarska 2013).

Different types of materials can be used as support for wood-based panels. The use of medium-density fiberboard (MDF) is justified by the fiber structure of the panel that makes a flat and uniform base for the veneer overlaying. The bond strength between the veneer and the MDF is influenced by a number of factors, including veneer species (Budakci 2010; Palija *et al.* 2018), MDF physical properties (*e.g.*, density, porosity, roughness, and moisture content (Martins *et al.* 2012)), adhesive type (Budakci 2010; Martins *et al.* 2012; Kureli and Doganay 2015), pressing parameters (Martins *et al.* 2012; Bastani *et al.* 2016), adhesive application amount (Budakci 2010), and MDF surface roughness (Ayrilmis *et al.* 2010; Kureli and Doganay 2015; Palija *et al.* 2018), as well as other factors.

When veneered MDF is used in the construction of paneled doors, the underlying frame is made of solid wood; different materials are used for the core filling (*e.g.*, paper honeycomb, extruded chipboard, softwood elements, *etc.*). Because the surface irregularities of the composite panel may show through the overlays (Ulker 2018), the flatness and fineness of the surface layer of the MDF are necessary for the overall quality of the veneered MDF panels. In previous research (Ozdemir *et al.* 2009), it was shown that the surface roughness of the MDF can increase when exposed to higher relative humidity (from 65% to 85%). In addition, the overall adhesion strength between the polyurethane finish and the MDF was adversely affected by increased surface roughness that was induced by higher relative humidity conditions.

In industrial conditions, non-uniform moisture content of individual components of door construction can lead them to swell or shrink, which thus causes increased or decreased MDF surface roughness. In relation to this effect, the use of moisture-resistant MDF (MR MDF) can help reduce panel swelling at the surface layer, especially with industrial conditions where interphase time buffers are common and consequently, exposure to moisture is prolonged. In contrast, the difference in the panel composition of MDF and MR MDF can affect the wetting properties of glue, which can consequently affect the bonding properties of a veneer-glue-panel. The differences in properties of MDF and MR MDF (*e.g.*, surface roughness and swelling or shrinking behavior) will be reflected in the surface properties of the resulting panels, which can impact the contact area between the veneer and substrate, and thus the bonding strength of the overall system.

Beside substrates, choosing a proper glue is an important step in production of veneered panels. In the wood industry, urea-formaldehyde (UF) adhesive is very often used, especially in the production of wood-based panels, veneering, and gluing of furniture elements (Dunky 2000). UF resins are noted for their high strength, rigidity, cost effectiveness, ease of use under a variety of curing conditions, low cure temperature and fast cure. A major disadvantage of UF resin is the lack of resistance to moist conditions, especially in combination with heat (Conner 1996). Instead of UF resin emulsion, small and medium capacity wood processing factories prefer to use the more convenient powder UF resin which can be prepared in a variety of concentrations just before use (Miljković *et al.* 2006).

In this paper, the impact of different pressing regimes on the bond strength of UF glued beech and oak veneers on MDF and MR MDF substrates was examined. A second aim was to examine whether it is possible to shorten the veneering pressing time in door production. Experiments in this study were conducted in real industrial conditions in the production of veneer-paneled doors. Additionally, experiments were conducted on the small-scale for door construction.

EXPERIMENTAL

Materials and Methods

The research on the influence of substrate type, veneer species, and pressing regime on bond strength was conducted in two phases. During the experimental phase, which was conducted at the Enterijer Janković factory in Novi Sad, Serbia, the veneered doors were produced. These doors were then transported to and examined at the laboratories of Belgrade University Faculty of Forestry (Belgrade, Serbia) along with non-veneered MDF and MR MDF samples.

Door frames were made from fir wood (*Abies alba* Mill.), mainly due to its physical and mechanical properties, and also because it is the most frequently used wood species for doors and windows in Serbia. The cross-section of the wood elements was 38 mm ×40 mm, and the wood elements were lap-joined using clamps. Hollow extruded chipboard

(Sauerlander Spanplatten GmbH & Co. KG, Arnsberg, Germany) that was 40 mm thick was used to make 524 mm × 324 mm door panels (Fig. 1). Hollow extruded chipboard provides a combination of low weight and good strength, which enables the production of high-quality doors that are not too heavy. Eight frames were made in total.

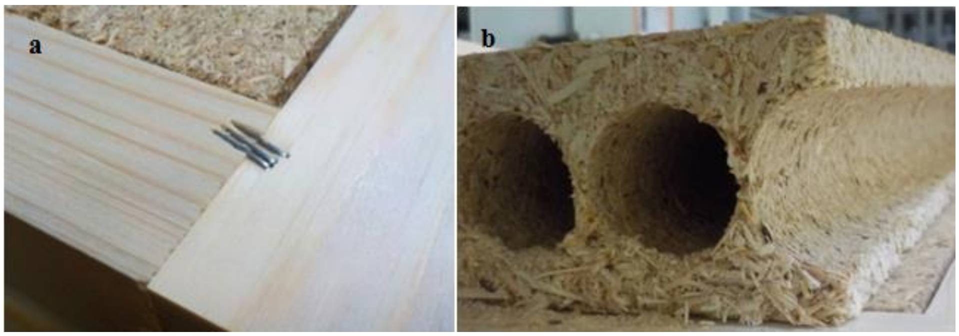

Fig. 1. Frame joint between fir wood elements (a) and hollow extruded chipboard (b)

Upper panels were made from boards (1600 mm × 600 mm × 6 mm); two of them were made from moisture-resistant MDF, whereas the other two were made from regular MDF (Sonae Arauco, Madrid, Spain). Urea-formaldehyde (UF) adhesive powder with built-in hardener, KleiberitUF 871.0 (Klebchemie M. G. Becker GmbH & Co. KG, Weingarten, Germany), was prepared using 100 mass portions of adhesive and 50 mass portions of water and applied using a glue roller coater at a rate of 130 g/m^2. Pressing of door components (*i.e.*, panels and frames with extruded chipboard) was conducted on a single-layer hydraulic press (Sormec, Alcamo, Italy). Both components were simultaneously pressed according to the following regime: 80 °C temperature, 0.7 MPa specific pressure, and 15 min pressing time.

The constructions were cut on a computer numerical control (CNC) cutter BiesseSelco WNT 6 (Biesse S.p.A., Pesaro, Italy). Calibration to the exact thickness was completed on a wide-belt sander (Egurko Ortza, Zumaia, Spain) with sand paper grit size no. 80, sanding speed 20 m/s, and sanding pressure 0.5 bar. The sanding was performed lengthwise on samples, in one run per each side. After cutting, eight doors (600 mm × 400 mm) were produced in two groups: four made with regular MDF and four made with MR MDF (Fig. 2). Doors were then dusted and blown clean to prepare them for veneering.

Fig. 2. Small-scale door construction from regular MDF (left) and moisture-resistant MDF (right)

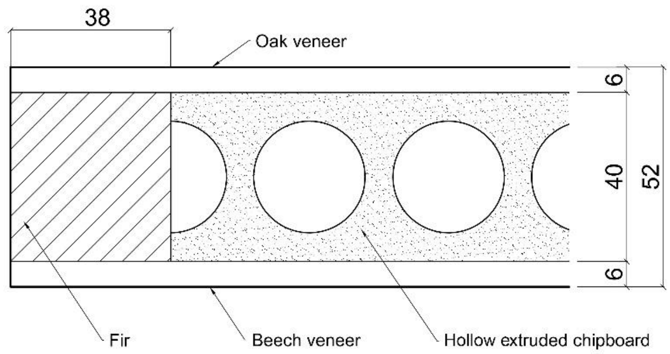

Fig. 3. Cross-section of door construction (dimensions in mm)

Panels were covered on the face side with oak veneer (0.6 mm thick (class I)) and on the backside with beech veneer (0.6 mm thick (class II)). The veneers (JAF Group, Stockerau, Austria) were sewn together in a zigzag pattern. The previously prepared UF glue (UF 871.0) was applied at an amount of 130 g/m^2 SGL (single glue line) on both panel sides simultaneously using a two-sided roller glue coater. Two panels were pressed at a time (one with regular MDF and one with MR MDF) over 4 cycles. Figure 3 shows the cross-section of the door construction.

Pressing was conducted on a VSF R9.8 press (Wemhöner, Herford, Germany) with six pistons by using four different pressing regimes (Table 1). The pressing at 100 °C during 3 min using specific pressure from 0.4 to 0.8 MPa was suggested by the UF adhesive manufacturer. Budakci (2010) obtained good results in gluing pine, oak, and beech veneers with UF adhesive on MDF substrate using the following pressing regime: specific pressure of 0.8 MPa at a temperature of 80 °C during 4 min. In order to examine whether if it was possible to shorten the pressing cycle in veneered door production, pressing time was reduced (from 4 to 2.5 min), while increasing specific pressure (from 0.7 to 1 MPa). The mildest regime was used for the first cycle of veneering, while in the final cycle the harshest regime was used.

The excess veneer was removed by hand after exiting the press. Final sanding (grit size no. 120) was completed on a wide-belt sander (Viet, Pesaro, Italy). After this step, experimental samples were cut. Samples were wrapped in stretch wrap and stored in controlled conditions at 20 ± 2 °C and 50 ± 5% relative humidity.

Table 1. Pressing Regimes

Regime Type	Temperature (°C)	Specific Pressure (MPa)	Open Time (s)	Close Time (s)	Pressing Time (min)	Exit Traveling Time (s)
R1	70	0.7	66	30	4.0	5
R2		1.0	45	10	2.5	5
R3	90	0.7	55	5	4.0	10
R4		1.0	43	3	2.5	10

Examination of the moisture content, density, and swelling of the MDF was conducted on 5 cm × 5 cm-sized samples according to the EN 322 (1993), EN 323 (1993), and ISO 13061-14 (2016) standards. Samples were first placed above water for 72 h. Then, they were submerged in water for 48 h to assess the behavior of regular MDF and MR MDF in high air humidity and over a long period of contact with water. The wettability of MDF and MR MDF with water was assessed by contact angle measurement using sessile drop method. The obtained data were fully processed using the statistical analysis software SPSS 20.0 (IBM Corp., Armonk, NY, USA).

Assessment of veneer bonding quality was conducted using test specimens (dollies) and a pull-out device according to the pull-out test standard ISO 4624 (2016). Dollies were first cleaned to remove any dirt and then glued onto the sample surfaces using 2K Bison Epoxy Universal glue (Bolton Group S.r.l., Milan, Italy).

After conditioning for 24 h and immediately before pulling out the samples, rings were cut into the veneers around the dollies using a hand cutter (model 15/16 24M/M; Morse, Master Cobalt, OH, USA) (Fig. 4a). The pull-out was done using a PosiTest AT-Adigital testing device (DeFelsko Corp., Ogdensburg, NY, USA) (Fig. 4b).

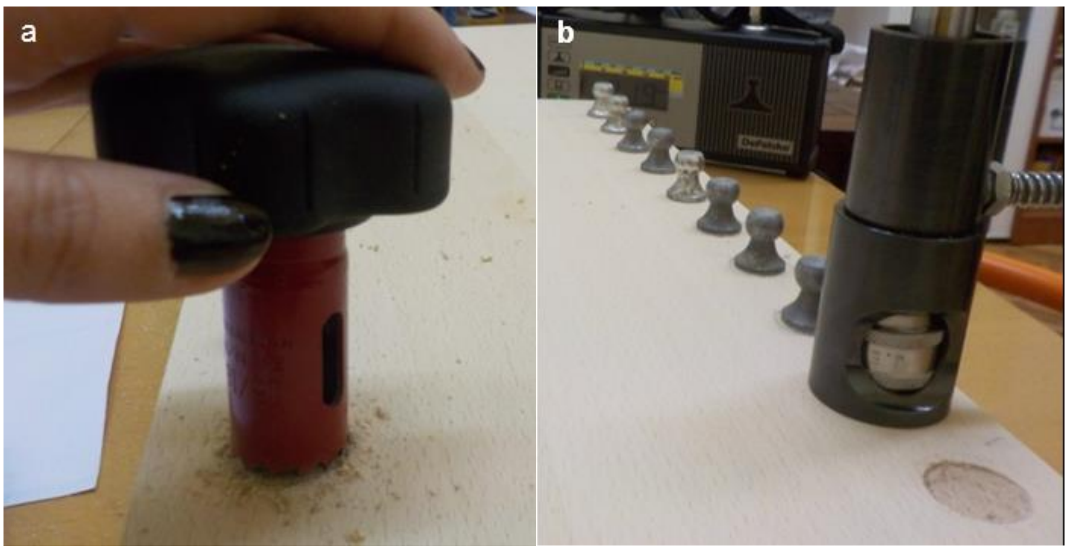

Fig. 4. Cutting veneer before the pull-out of dollies (a) and removal of dollies (b)

RESULTS AND DISCUSSION

Tables 2 and 3 present the results of examining the bonding strength between the beech or oak veneer and the substrates (*i.e.*, regular and MR MDF). Bonding strength ranged between 1.34 and 2.42 MPa; both these values were observed with the beech veneer glued using the R2 process onto different surfaces. The experimental combination with the lowest bonding quality (of 1.34 MPa) also showed the highest coefficient of variation of all (20.62). Normality distribution testing showed that all of the analyzed mean values had normal distributions and similar variations. More detailed statistical analyses were performed using the SPSS 20.0 software as shown in the tables.

To establish whether there were significant differences in bonding strength between the oak and the beech veneers (regardless of substrate type), individual samples were examined through the Student's t-test. Results indicated a significant difference ($t(280) = -5.372$ and $p < 0.001$) in the way that the oak veneer required a higher force ($F = 2.02$ and standard deviation (SD) = 0.30) compared to the beech veneer ($F = 1.78$ and $SD = 0.46$). These differences were attributed to different anatomical and physical properties of the examined veneer species.

Table 2. Basic Statistical Parameters for Bonding Strength of Beech Veneer Correlated to the Type of MDF and the Pressing Regime

Veneer Type	**Beech**							
Type of MDF	**Regular MDF**				**MR MDF**			
Regime	**R1**	**R2**	**R3**	**R4**	**R1**	**R2**	**R3**	**R4**
Mean Value (MPa)	2.20	2.42	2.21	1.96	1.43	1.34	1.47	1.41
Standard Deviation (MPa)	0.19	0.24	0.24	0.17	0.17	0.28	0.22	0.14
Variation (MPa)	0.04	0.06	0.06	0.03	0.03	0.08	0.05	0.02
Coef. of Variation (MPa)	8.66	9.87	10.67	8.61	12.09	20.62	14.74	9.93
Standard Error (MPa)	0.04	0.06	0.07	0.04	0.04	0.07	0.05	0.03

Table 3. Basic Statistical Parameters for Bonding Strength of Oak Veneer Correlated to the Type of MDF and the Pressing Regime

Veneer Type	**Oak**							
Type of MDF	**Regular MDF**				**MR MDF**			
Regime	**R1**	**R2**	**R3**	**R4**	**R1**	**R2**	**R3**	**R4**
Mean Value (MPa)	2.32	2.03	2.08	2.15	2.22	1.73	1.60	2.07
Standard Deviation (MPa)	0.19	0.20	0.22	0.17	0.22	0.21	0.15	0.19
Variation (MPa)	0.04	0.04	0.05	0.03	0.05	0.04	0.02	0.03
Coef. of Variation (MPa)	8.17	10.00	10.79	8.06	10.07	12.09	9.46	9.00
Standard Error (MPa)	0.04	0.05	0.05	0.04	0.05	0.05	0.04	0.04

Because wood density is the highest-impacting factor relative to swelling (Kollmann 1968), it is possible that veneer made from beech (the more dense wood) suffered from more tension after contact with water from urea-formaldehyde (UF) glue and that this negatively affected the bonding strength. The anatomical differences between these two species also should not be ignored. The surface characteristics of the wood veneer are inevitably influenced by the hot compression treatment (Li *et al.* 2014). In addition, an analysis of the curing of the UF glue on wood substrate (Siimer *et al.* 2006) indicated that wood substrate can change the water and resin diffusion characteristics during the adhesive curing, which can also be attributed to different influences from different wood species.

This observation contradicts a previous research study of the influence of sanding on the bonding strength between MDF and veneers from different wood species (Palija *et al.* 2018), where the beech veneers had higher bonding strength (2.40 MPa) than oak veneer (2.21 MPa). It also contradicts the results of Kureli and Doganay (2015), where beech veneer also showed greater bonding strength (2.58 MPa) than oak veneer (2.58 MPa) on sanded MDF substrate. The reason for this could be that different glue types, different pressing regimes (*i.e.*, polyvinyl acetate (PVAc) glue, 90 °C, 0.7 MPa specific pressure, and 5 min (Palija *et al.* 2018)), and different pressing pressures (0.8 MPa (Kureli and Doganay 2015)) were used. This confirms that it is not advisable to consider only the bonding strengths between MDF and veneer without taking into account the glue type and the pressing regime.

Student's t-test of individual samples also showed that regular MDF (F = 2.18 and SD = 0.24) had higher bonding quality ($t(280) = 13.980$ and $p < 0.001$) than the moisture-resistant MDF (F = 1.66 and SD = 0.36). This was explained by the different properties of MDF and MR MDF. The surface chemistry of MDF will interfere with wetting, flowing, and penetrating of the adhesive (Martins *et al.* 2012). Weak wetting and weak penetrating of the glue into the substrate tended to affect the bond strength adversely, which was probably the main reason why the bond strength with MR MDF was much lower.

To compare the differences of bonding strength between different types of veneers and MDF, a variation analysis was conducted, and it exposed significant differences ($F(3, 278) = 144.063$ and $p < 0.001$). The Tukey's honest significant difference (HSD) *post-hoc* analysis showed significant differences among all the paired comparisons, except for the beech veneer glued onto regular MDF *versus* the oak veneer glued onto regular MDF.

The MR MDF substrate was observed to have the weaker glued veneers (Figs. 5 and 6), which represented the results of examination of the influence of substrate type and the applied pressing regime (for beech and oak veneers, respectively).

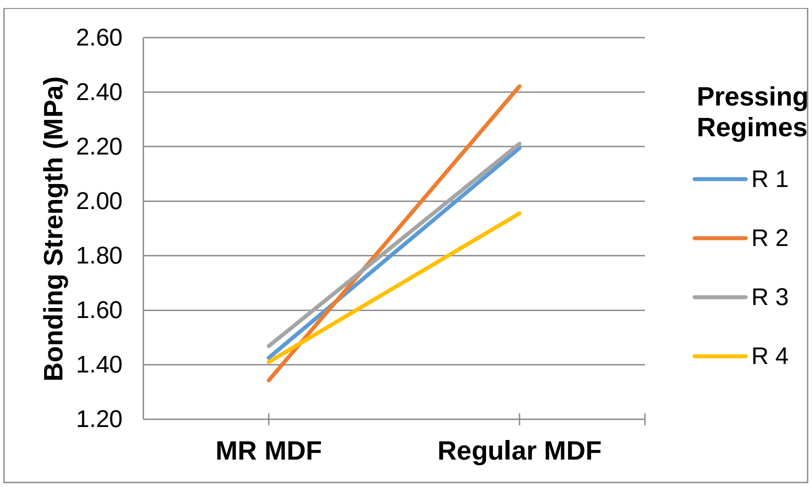

Fig. 5. Influence of substrate type and pressing regime on the bonding strength of beech veneer

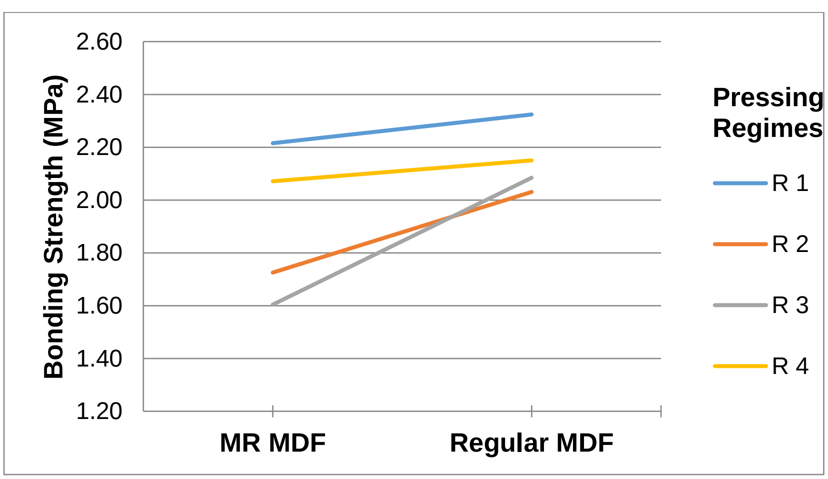

Fig. 6. Influence of substrate type and pressing regime on the bonding strength of oak veneer

In all the glued couples, the moisture-resistant MDF was the weaker substrate, with the beech veneer having the largest difference. Contact angle measurements in exposing to droplets of water after 10 and 40 seconds confirmed weak wetting of MR MDF. Regular MDF showed significantly lower ($t(28) = -3.444$ and $p < 0.01$; $t(28) = -5.518$ and $p < 0.001$) contact angle values. The average contact angle (θ) for regular MDF after 10 s was 89.7°, and after 40 s it was 82.1°, compared to MR MDF where average contact angle was 98.7° and 97.3°, after 10 and 40 seconds, respectively. Weak wetting and weak penetration of the UF glue into the moisture-resistant MDF, as well as greater dimension changes of the beech veneer compared to the oak veneer and their anatomical differences, were probably the reasons behind the lowest bonding strength being observed between these two materials.

The influence of pressing regimes on bonding strength was examined by multivariate analysis of variance (ANOVA) and Tukey's HSD *post-hoc* tests. When observed without the influence of substrate type and veneer species, the various pressing regimes (Fig. 7) showed significant differences ($F(3, 278) = 3.775063$ and $p < 0.05$). Tukey's HSD *post-hoc* only indicated that there were higher differences in the bonding strengths with R1 and R3 processes.

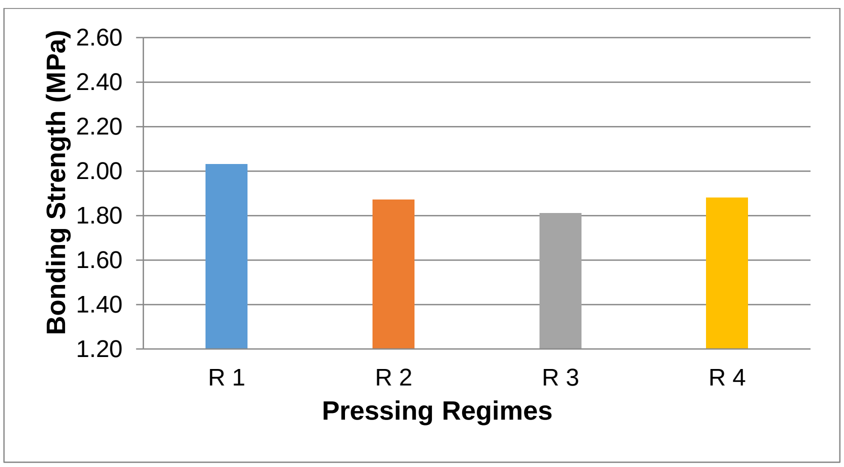

Fig. 7. Influence of pressing regime on the bonding strength regardless of substrate type or veneer species

Results were different when the veneer species and substrate types were included in the statistical analyses (Figs. 8 and 9). Beech veneer (Fig. 8) showed significant differences in bonding strength ($F(7, 132) = 78.496$ and $p < 0.001$), while all the regimes on regular MDF produced much better bonding quality *versus* any pressing regime on MR MDF. When the regimes with beech veneer on the regular MDF were compared, the first three regimes produced higher bonding strengths than the fourth. The regime R2 (70 °C, 1 bar, and 2.5 min), showed significantly better results ($F = 2.42$ and $SD = 0.24$), than R1 ($F = 2.19$ and $SD = 0.19$); however, there was no significant difference when compared to R3. Because the difference in average pull-out resistance between R1and R3 was just 0.02 MPa, it can be safely concluded that R1, R2, and R3 produced equal bonding strengths of beech veneer glued on to regular MDF, whereas the combination of higher temperature and higher pressure of R4 resulted in lower values. When MR MDF was used, all the regimes produced a similar weak bonding strength of approximately 1.5 MPa.

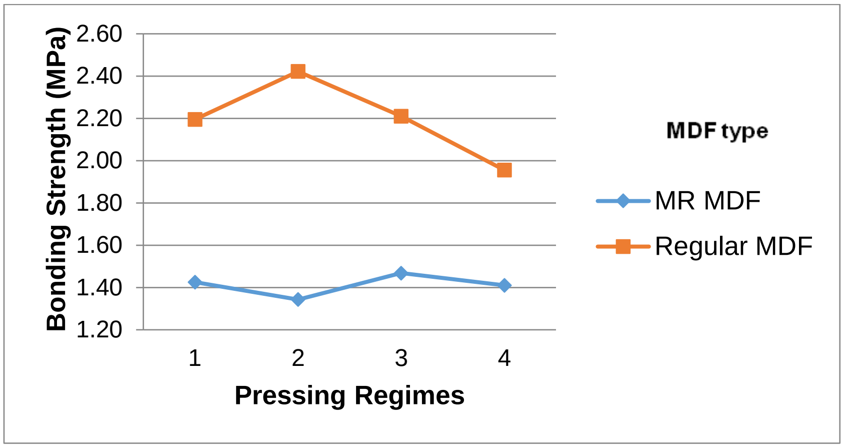

Fig. 8. Influence of substrate type and pressing regime on the bonding strength of beech veneer

Oak veneer (Fig. 9) also resulted in significant differences in bonding strength ($F(7, 134) = 27.896$ and $p < 0.001$); however, these differences appeared in different places in the experimental space than with the beech veneer. On regular MDF substrate, the best results were observed with R1. On the moisture-resistant MDF, R1 and R4 yielded better bonding quality than R2 and R3.

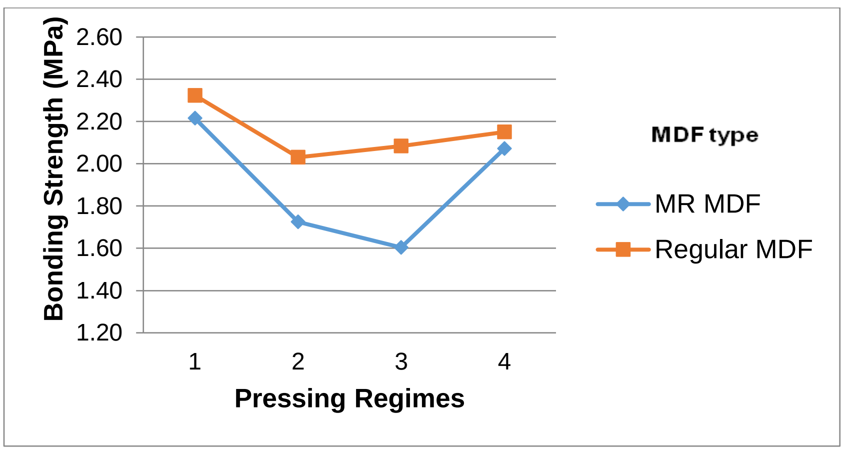

Fig. 9. Influence of substrate type and pressing regime on the bonding strength of oak veneer

Because R1 and R4 produced similar results of bonding strength on both substrates, it was concluded that the oak veneer was impacted much more by the pressing regime used than by substrate type for both MDF and MR MDF. The R1 (70 °C, 7.0 MPa, and 4 min) and R4 (90 °C, 1.0 MPa, and 2.5 min) produced the best results. These results could be highly important during industrial production because similar bonding strength could be achieved by either using lower temperature and lower pressure at a longer time or using higher temperature and higher pressure for a shorter time. Economical benefits of R1and R4 would require further analyses, but it seems that productivity would be increased by using R4.

In addition, the resulting changes of dimensions of regular MDF and MR MDF could be of practical significance (Table 4). Even with significantly higher density ($t(33) = 22.299$ and $p < 0.001$), the regular MDF exhibited less swelling after 72 h above water ($t(33) = -6005$ and $p < 0.001$), but it exhibited more swelling after 48 h submerged in water (t(33) = 9.705 and $p < 0.001$). Although it is unusual, the lesser swelling of regular MDF after 72 h above water can be a result of the MDF production process. The surface density of regular MDF is usually much higher than surface density of MR MDF, and greater surface density can represent a barrier for water vapor, but not for water.

Table 4. Density and Swelling of Regular and MR MDF in High Air Humidity and After Submerging

Type of MDF	Regular MDF			MR MDF		
Physical Properties	Density (kg/m^3)	Swelling After 72 h Above Water (%)	Swelling After Submerging In Water (%)	Density (kg/m^3)	Swelling After 72 h Above Water (%)	Swelling After Submerging In Water (%)
Mean Value	0.885	9.280	37.629	0.677	11.339	27.530
Standard Deviation	0.03	0.789	3.982	0.024	1.237	0.599
Variation	0.001	0.622	15.886	0.001	1.531	0.359
Coef. of Variation	3.360	8.500	10.582	3.520	10.913	2.176
Standard Error	0.007	0.176	0.890	0.006	0.319	0.155

In the usual use of veneered panels, their behavior in conditions of varying air humidity is of much higher importance than their behavior in constant contact with water. This is why the observed lower swelling with moisture-resistant MDF should not be crucial when choosing the veneering substrate, especially because all of the changes of dimensions (by larger than 20%) lead to significant losses in board strength (Jaić and Živanović-Trbojević 2000). When this is added to the observed lower quality of the bond, it was concluded that MR MDF should only be used when extreme changes in humidity are expected during the use of the veneered product.

However, this conclusion should not be generalized. In this research, only a single type of regular MDF and a single type of MR MDF were used. The higher swelling of MR MDF in conditions of high air humidity could have been caused by the lower density of MR MDF (0.677 g/cm^3) *versus* regular MDF (0.885 g/cm^3). Besides this attribute, a lower-quality MDF can have variable density across its surface (Palija *et al.* 2018). These variations can make the layer of applied adhesive uneven, which leads to easier splitting during the assessment of veneer bonding quality.

CONCLUSIONS

1. If the examined factors are considered separately, higher bonding strength was achieved with oak veneer *versus* beech veneer, as well as using regular MDF *versus* moisture-resistant MDF.
2. Weak wetting and penetrating of the UF glue, and less mechanical glue interlocking with the veneer with the MR MDF, as well as larger dimension changes of beech veneer compared to oak veneer, probably caused weak bond between these two materials.
3. First, three pressing regimes (R1, R2, and R3) when using beech veneer and regular MDF produced similar results; the combination of higher temperature and higher pressure (*i.e.*, R4) yielded lower bonding strength. The MR MDF substrate produced

equally weak veneer bonding strength of approximately 1.5 MPa among all four pressing regimes.

4. When using oak veneer, the pressing regime used had a higher impact than the substrate type; with both regular MDF and MR MDF, R1 (70 °C, 0.7 MPa, and 4 min) and R4 (90 °C, 1.0 MPa, and 2.5 min) yielded the best results. Similar bonding strength could be achieved either by using a lower temperature and lower pressure at a longer time, or by using a higher temperature and higher pressure for a shorter time (where productivity could be increased).
5. Higher swelling in high humidity conditions and weaker bond strength indicated that the moisture-resistant MDF should only be used when extreme changes of humidity are expected during the use of the veneered product. To confirm this finding, their behavior in the long-term conditions should also be examined.

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REFERENCES CITED

Ayrilmis, N., Candan, Z., Akbulut, T., and Balkiz, O. D. (2010). “Effect of sanding on surface properties of medium density fiberboard,” *Drvna Industrija* 61(3), 175-181.

Bastani, A., Militz, H., Adamopoulos, S., and Rohuma, A. (2016). “Development of bonding strength of modified birch veneers during adhesive curing,” *Wood Research* 61(2), 205-214.

Budakci, M. (2010). “The determination of adhesion strength of wood veneer and synthetic resin panel (laminate) adhesives,” *Wood Research* 55(2), 125-136.

Conner, A. H. (1996). “Urea-formaldehyde adhesive resins,” in: *Polymeric materials encyclopedia*, Forest Product Laboratory, CRC Press, United States of America.

Dunky, M. (2000). “Urea-formaldehyde (UF) glue resins: An adhesive ever young,” in: *Proceedings of The 5th Pacific Rim Bio-Based Composites Symposium*, Canberra, Australia, pp. 205-213.

EN 322 (1993). “Wood-based panels – Determination of moisture content,” European Committee for Standardization, Brussels, Belgium.

EN 323 (1993). “Wood-based panels – Determination of density,” European Committee for Standardization, Brussels, Belgium.

ISO 4624 (2016). “Paints and varnishes – Pull-off test for adhesion,” International Organization for Standardization, Geneva, Switzerland.

ISO 13061-14 (2016). Physical and mechanical properties of wood – Test methods for small clear wood specimens – Part 14: Determination of volumetric shrinkage,” International Organization for Standardization, Geneva, Switzerland.

Jaić, M., and Živanović-Trbojević, R. (2000). “Wood and wood based panels as a substrate for surface treatment,” in: *Wood Surface Treatment: Theoretical*

Foundations, Technological Processes, University of Belgrade, Belgrade, Serbia, pp. 18-21.
Kollmann, F. F. P. (1968). "Physics of wood," in: *Principles of Wood Science and Technology I - Solid Wood*, F. F. P. Kollmann and W. A. Cote, Jr. (eds.), Springer-Verlag, New York, NY, USA, pp. 160-291. DOI: 10.1007/978-3-642-87928-9_6
Kureli, I., and Doganay, S. (2015). "The effects of surface roughness, adhesive type, and veneer species on pull-off strength of laminated medium density fibreboard," *BioResources* 10(1), 1293-1303. DOI: 10.15376/biores.10.1.1293-1303
Li, W., Wang, C., Zhang, Y., Jia, C., Gao, C., and Jin, J. (2014). "The influence of hot compression on the surface characteristics of poplar veneer," *BioResources* 9(2), 2808-2823. DOI: 10.15376/biores.9.2.2808-2823
Martins, J., Coelho, C., Ferra, J., Cruz, P., and Carvalho, L. (2012). "Low formaldehyde emission MDF overlaid with wood veneer: Bonding problems assessment," *International Wood Products Journal* 3(1), 31-35. DOI: 10.1179/2042645312Y.0000000005
Miljković, J., Gavrilović-Grmuša, I., Điporović-Momčilović, M., and Popović, M. (2006) "Some characteristics of urea-formaldehyde powder adhesives," *Glasnik šumarskog fakulteta* 94, 223-230.
Ozarska, B. (2013). "Advantages of the use of veneered panels in wood products," in*: A Manual for Decorative Wood Veneering Technology*, Forest & Wood Products Australia, Melbourne, Australia, pp. 17-18.
Ozdemir, T., Hiziroglu, S., and Malkocoglu, A. (2009). "Influence of relative humidity on surface quality and adhesion strength of coated medium density fiberboard (MDF) panels," *Materials & Design* 30(7), 2543-2546. DOI: 10.1016/j.matdes.2008.09.036
Palija, T., Zdravković, V., and Obradović, A. (2018). "The impact of wood veneer species on its adhesion strength on surface of medium density fibreboard," in: *Proceedings of the International Forest Products Congress - ORENKO*, Trabzon, Turkey, pp. 271-278.
Siimer, K., Kaljuvee, T., Christjanson, P., and Lasn, I. (2006). "Curing of urea-formaldehyde resins on a wood substrate," *Journal of Thermal Analysis and Calorimetry* 84(1), 71-77. DOI: 10.1007/s10973-005-7185-7
Ulker, O. (2018). "Surface roughness of composite panels as a quality control tool," *Materials* 11(3), 1-10. DOI: 10.3390/ma11030407

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